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(54) **METHOD AND APPARATUS FOR CONTROLLING A JET PUMP**

(57) **Abstract:**

This invention relates to a method and apparatus to adjust or control a jet pump of the type having a compressible flow in the diffusor and a supercritical ratio of suction to discharge pressures.

In a jet pump of this type, the mixture of the motive or thrust stream which in most instances will be steam, and the suction stream flows initially at a supersonic velocity. The change from supersonic to subsonic velocity of the thrust and suction stream will occur in a shock zone. This shock zone will be displaced in a direction toward the thrust nozzle when the reaction or back pressure increases or when the thrust pressure or thrust flow decreases. Once this shock zone moves into the intake cone of the diffusor, the jet pump becomes unstable in operation and the pumping action can fail completely. In a similar manner when the reaction or back pressure decreases or thrust flow increases, the shock zone will be displaced into the exit cone of the diffusor. With the shock zone in the exit cone of the diffusor, the rate of flow of the mixture of thrust and suction streams is accelerated increasing the pressure drop across the diffusor and decreasing the efficiency of the jet pump. The lowest ratio of flow of thrust fluid to flow of the suction fluid is attained when the jet pump is just about in stable operation which is when the shock zone is in the throat of the diffusor or just at

the beginning of the diffusor outlet cone.

In daily actual operation of jet pumps of this type, variations in back pressure as well as variations in the pressure of the thrust stream do occur. Prior to the present invention, to avoid such a jet pump from reaching an unstable operation the jet pump was operated with an excess amount of thrust stream flow to take care of the maximum back pressure which could occur and the minimum thrust stream pressure which could occur. Consequently, it will be seen that prior to the present invention, jet pumps of this type operated most of the time with an excessive use of thrust fluid.

With the foregoing in mind, a primary object of the present invention is to provide means for controlling or regulating a jet pump of this type to permit the shock zone to remain in the optimum performance position regardless of fluctuations of back pressure or thrust stream pressure. This is acceomplished in the present invention by using a measurement of a condition of the stream of thrust and suction fluids within the throat of the diffusor as a means for regulating the rate of flow of the thrust stream to maintain the shock zone in the throat of the diffusor. The condition of the stream of thrust and suction fluids in the diffusor used to control the rate of flow of the thrust stream fluid can be a measurement of the static pressure gradient along the diffusor, the velocity gradient along the diffusor or a temperature gradient along the diffusor.

The various features and details of the present invention will be more fully described with reference to the accompany- drawings in which:

Fig. 1 is a schematic illustration of the thrust stream nozzle and diffusor of a jet pump with static pressure taps spaced along the diffusor in an area adjacent the throat of the diffusor;

Fig. 1*a* is a graph showing the static pressure along the diffusor axis with the shock zone at designated points in the diffusor;

Fig. 2 is a schematic illustration of the thrust stream nozzle and diffusor of a jet pump with a series of pitot tube pressure taps for measuring the velocity of flow at predetermined points along the diffusor;

Fig. 2*a* is a chart showing the relationship of the pitot tube pressure along the diffusor axis with the shock zone at designated locations within the diffusor; and

Fig. 3 is a schematic diagram of a jet pump together with a control system for controlling the jet pump in accordance with the method of the present invention.

The jet pump to which the present invention is applied comprises a conventional nozzle 10 including an adjustable spindle 11 to control the flow of the thrust medium and a diffusor 12 having an inlet cone 13, a throat portion 14 and an outlet cone 15. A reversible motor 16 is provided to move the spindle back and forth relative to the thrust nozzle 10 to control the rate of flow of the thrust medium. Steam or other thrust medium will be supplied to the jet pump through an inlet pipe 17 leading to the nozzle 10. A conduit 18 leading into a chamber 19 surrounding the thrust nozzle 10 is connected to the source (not shown) of the suction stream. The exit of the outlet cone of

the diffusor may be connected to the condensation and gas separating tank 20 in which the thrust fluid is separated from the suction fluid.

Referring specifically to Figs. 1 and 1a, there is shown the static pressure along the diffusor when the shock wave or transition zone between supersonic and subsonic flow of the mixture of thrust and suction mediums is at points A through G, respectively. In addition, in Fig. 1 there are static pressure taps P_1, P_2, P_3, and P_4 as shown in the throat of the diffusor and the inlet end of the outlet cone.

It will be seen from Fig. 1a that the static pressure is substantially constant throughout the length of the throat of the diffusor to the shock wave at which point the static pressure increases abruptly. Also, as shown in Fig. 1a, the static pressure will decrease in the outlet cone of the diffusor from the exit of the throat of the diffusor to the point where the shock wave exists at which time the static pressure will abruptly increase and thereafter increase substantially uniformly throughout the length of the outlet cone.

Thus, for example, if it is desired to maintain the shock wave at position C which is directly at the pressure static tap P_2, the pressure at the pressure static tap will be as shown at P_{2c} in Fig. 1a. If the back pressure increases or the pressure of the thrust fluid decreases, the shock wave will be moved to the left with respect to P_2 and the pressure at P_2 will abruptly increase. Similarly, if the back pressure would decrease or the thrust pressure increase, the shock wave will be moved to the right with respect to P_2 and the pressure at P_2 will

abruptly decrease. Accordingly, by maintaining the pressure at P_2 constant, and maintaining this pressure as shown at P_{2C}, the shock wave will be maintained at Position C.

Similarly, the static pressure gradient at the outlet of the throat and inlet end of the outlet cone of the diffusor may be used to control the position of the shock wave when it is desired to maintain the shock wave in an optimum position between two static pressure taps. It is evident, for example, if the shock waves were at Position D, the pressure differential between P_2 and P_3 would be as shown at points P_{2D} and P_{3D} in the chart of Fig. 1a. Should the shock wave move forwardly in the outlet cone, for example, to E, the pressure differential between P_2 and P_3 would change to that as shown at P_{2E} and P_{3E} in Fig. 1a. The following table shows the pressure gradient measured at three points---P_1, P_2, and P_3 in Fig. 1 as the shock wave moves through positions A, B, D and G.

SHOCK ZONE POSITION	PRESSURE GRADIENT
A	$P_1 < P_2 < P_3$
B	$P_1 < P_2 < P_3$
D	$P_1 > P_2 < P_3$
G	$P_1 > P_2 > P_3$

Should it be desired to maintain the shock wave at position D, it can be seen that the flow of thrust medium must be increased when P_1 is greater than P_2 but must be reduced when P_2 is less than P_3 until the condition in which P_1 is greater than P_2 which in turn less than P_3 is obtained. If it is desired to use four measuring points P_1, P_2, P_3, and P_4 the pressure gradients between these measuring points for shock wave positions at A, B

D, F, and G are as follows:

SHOCK ZONE POSITION	PRESSURE GRADIENT	
A	$P_1 < P_2$	$P_3 < P_4$
B	$P_1 < P_2$	$P_3 < P_4$
D	$P_1 > P_2$	$P_3 < P_4$
F	$P_1 > P_2$	$P_3 < P_4$
G	$P_1 > P_2$	$P_3 > P_4$

Again, a desired condition for regulating flow of thrust medium is when the shock wave is at point D utilizing these above points. When the shock wave is at Position D, P_1 is greater than P_2 and P_3 is less than P_4. When P_1 becomes less than P_2 the flow of thrust medium must be increased and when P_3 becomes greater than P_4 the flow of thrust medium must be decreased.

Fig. 3 illustrates schematically a control system for carrying out the method of the present invention. In the system of Fig. 3 there are three static pressure taps 21, 22 and 23 which correspond to the pressure taps P_1, P_2 and P_3 described above. Also in this system, it is desired to maintain the shock wave at Position D' which corresponds to the Position D of Fig. 1.

In the control system of Fig. 3, the static pressure taps 21, 22 and 23 are connected to two similar pressure-responsive switches 24 and 25. The position of the switches 24 and 25 is controlled by spring biased diaphragms 26 and 27, respectively. With equal pressure on both sides of the diaphragm, the switches 24 and 25 are in the position as shown in Fig. 3 with a circuit completed through the contacts 24<u>a</u> and 25<u>a</u>, respectively, of the switches. A conduit 28 connects the pressure

tap 21 with one side of the diaphragm 26 of the switch 24 and a conduit 29 connects the pressure tap 23 with one side of the diaphragm 27 of the switch 25. A common conduit 30 connects the pressure tap 22 with the other sides of the diaphragms 26 and 27.

In operation as the jet pump of the present invention is initially turned on, the spindle 11 will be in its fully retracted position permitting the maximum flow of motive stream through the nozzle 10. In any position of the shock wave within the inlet cone 13 or in the throat 14 of the diffusor upstream of the pressure tap 22, the pressure at the tap 21 will be less than the pressure at the tap 22 which in turn will be less than the pressure at the tap 23. With this pressure relationship between the taps 21, 22 and 23, the switch 24 will be in the position as shown in Fig. 3 with a circuit completed through the contact 24a and the switch 25 will be in a position with the circuit completed through the contact 25b. With the switches in this position, a circuit is completed through the switch 24 to the contact R of the motor 16 causing the motor 16 to retract the spindle 11. As the shock wave moves past the pressure tap 22, for example, to the position shown in D' in Fig. 3, the pressure at the tap 21 is greater than the pressure at the tap 22 which in turn is less than the pressure at tap 23. With this pressure relationship existing, the switch 24 will be in a position wherein the circuit is completed through contact 24b and the switch 25 will be in a position wherein the circuit is completed through contact 25b. With the switches in these positions, no circuit will be completed to the motor 16 and thus, the spindle will remain in the position it is in when the shock wave reaches

osition D'. Should the shock wave move into the outlet cone 15 of the diffusor to a position downstream of the pressure tap 23, the pressure at the tap 21 will be greater than the pressure at tap 22 which in turn will be greater than the pressure at tap 23. With this pressure relationship existing, the switch 24 will be in a position in which circuit is completed through the contact 24b and the switch 25 will be in a position wherein the circuit is completed through the contact 25a. With the switches 24 and 25 in this position, a circuit is completed through the switches 24 and 25 to the contact F of the motor 16 which causes the motor to drive the spindle 11 forward throttling the motive stream passing through the nozzle 10 and decreasing the rate of flow of the motive stream. Decreasing the rate of flow of the motive stream will cause the shock wave to move in a direction upstream of the diffusor until the shock wave reaches the previously defined position D' between the pressure taps 22 and 23 at which time operation of the motor 16 will halt. Thus, it will be seen that this control system of Fig. 3 will cause the shock wave to assume a position at D' and maintain the shock wave at this position. Should conditions within the system be such as to cause the shock wave to move away from this position, the control system will compensate for these conditions and move the shock wave back to the position D'.

Referring now to Figs. 2 and 2a, there is shown the pitot tube pressure along the diffusor when the shock wave or transition zone between supersonic and subsonic flow of the mixture of thrust and suction mediums is at points A through G respectfully. In addition, In Fig. 2 there are pitot tubes

P_{i1}, P_{i2}, P_{i3}, and P_{i4} as shown in the inlet end of the outlet cone of the diffusor.

It will be seen from Fig. 2a that the pitot tube pressure is substantially constant throughout the throat of the diffusor and is substantially constant downstream of the shock wave in the outlet cone. However, the pitot tube pressure drops uniformly from the inlet end of the outlet cone to the position of the shock wave. It is evident, for example, if the shock waves were at Position B, the pressure at P_{i1} would be greater than the pressure at P_{i2} as shown at P_{i1B} and P_{i2B} in Fig. 2a and that the pressure at P_{i3} and P_{i4} will be the same as the pressure at P_{i2}. Also, if the shock wave were at Position D, the pressure at P_{i2} will be as shown in P_{i2D} in Fig. 2a which will be less than the pressure at P_{i1} but greater than the pressure at P_{i3}.

The following table shows the pressure gradient for three points of measurements P_{i1}, P_{i2}, and P_{i3} as the shock wave moves through positions A, B, D and G.

SHOCK WAVE ZONE	PRESSURE PROGRESS
A	$P_{i1} = P_{i2} = P_{i3}$
B	$P_{i1} > P_{i2} = P_{i3}$
D	$P_{i1} > P_{i2} > P_{i3}$
G	$P_{i1} > P_{i2} > P_{i3}$

The shock wave position at B is the optimum position and it can be seen that P_{i1} is greater than P_{i2} and that when P_{i2} is equal to P_{i3}, the shock wave is at the point B. If P_{i1} becomes equal to P_{i2} the volume of the motive stream must be increased. Similarly, if P_{i2} becomes greater than P_{i3}, the volume of the motive stream must be decreased. Thus, this pressure differential

may be used to provide a control signal to control the flow of the motive stream. If it is desired to use four measuring points P_{i1}, P_{i2}, P_{i3}, and P_{i4} the pressure gradients between these measuring points for shock wave positions A, B, D, F and G are as follows:

SHOCK WAVE POSITION	PRESSURE GRADIENT
A	$P_{i1} = P_{i2}$ $P_{i3} = P_{i4}$
B	$P_{i1} > P_{i2}$ $P_{i3} = P_{i4}$
D	$P_{i1} > P_{i2}$ $P_{i3} = P_{i4}$
F	$P_{i1} > P_{i2}$ $P_{i3} > P_{i4}$
G	$P_{i1} > P_{i2}$ $P_{i3} > P_{i4}$

With four measuring points, it will be possible to maintain the shock wave positions between B and D. For example, when P_{i1} becomes equal to P_{i2} the flow of motive stream must be increased and when P_{i3} becomes greater than P_{i4} the flow of motive stream must be reduced.

Only one example has been given of a control system utilizing pressure differentials or pressure gradient throughout the diffusor to control the position of the shock wave. However, it can be seen that when using static pressure taps or pitot tube taps, there are pressure gradients in the diffusor which can be used to provide a control signal to control the flow of motive stream which in turn will control the position of the shock zone within the diffusor.

While particular embodiments of the present invention have been illustrated and described herein, it is not intended to limit the invention to such a disclosure and changes and modifications may be incorporated and embodied therein within the soope of the following claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a control system for a jet pump in which the stream of motive fluid and suction fluid initially flows at a supersonic velocity and is converted at a shock wave within said jet pump to sonic velocity; said jet pump having a diffusor including a central throat portion, an inlet cone converging inwardly toward the central throat, an outlet cone diverging outwardly away from the central throat, an inlet to said inlet cone in fluid communication with said suction medium, an adjustable nozzle adjacent the inlet to said inlet cone for supplying said thrust medium, and adjusting means for said nozzle to control the flow of said thrust medium; a plurality of pressure taps spaced longitudinally of said diffusor to measure pressure at preselected points spaced longitudinally of said diffusor, one of said pressure taps positioned to measure pressure in said throat at one of said preselected points closely adjacent said outlet cone, and at least two of said pressure taps positioned in longitudinally spaced relation in said outlet cone with the first of said two pressure taps spaced a preselected distance from said throat to measure pressure at a first preselected point in said outlet cone and the second of said two pressure taps spaced from said throat further than said preselected distance to measure pressure at a second preselected point in said outlet cone; and control means operatively connected to said adjusting means for said nozzle, said control means responsive to the pressure measured by said plurality of pressure taps to adjust said nozzle to maintain the transition shock wave between supersonic and sonic velocity of said stream of motive and suction fluids between said one preselected point in said throat and said second preselected point in said outlet cone.

2. A control system in accordance with Claim 1 in which said control means operates to open said nozzle to increase the flow of thrust fluid when said shock wave is between said nozzle and said first preselected point in said outlet cone and operates to close said nozzle when said shock wave is beyond said second preselected point in said outlet cone in a direction away from said first shock wave between said first and second preselect-

ed points in said outlet cone.

3. A control system for a jet pump in accordance with Claim 2, wherein said pressure taps are static pressure taps.

4. A control system for a jet pump in accordance with Claim 2, wherein said pressure taps are pitot tube pressure taps.

FIG.3.

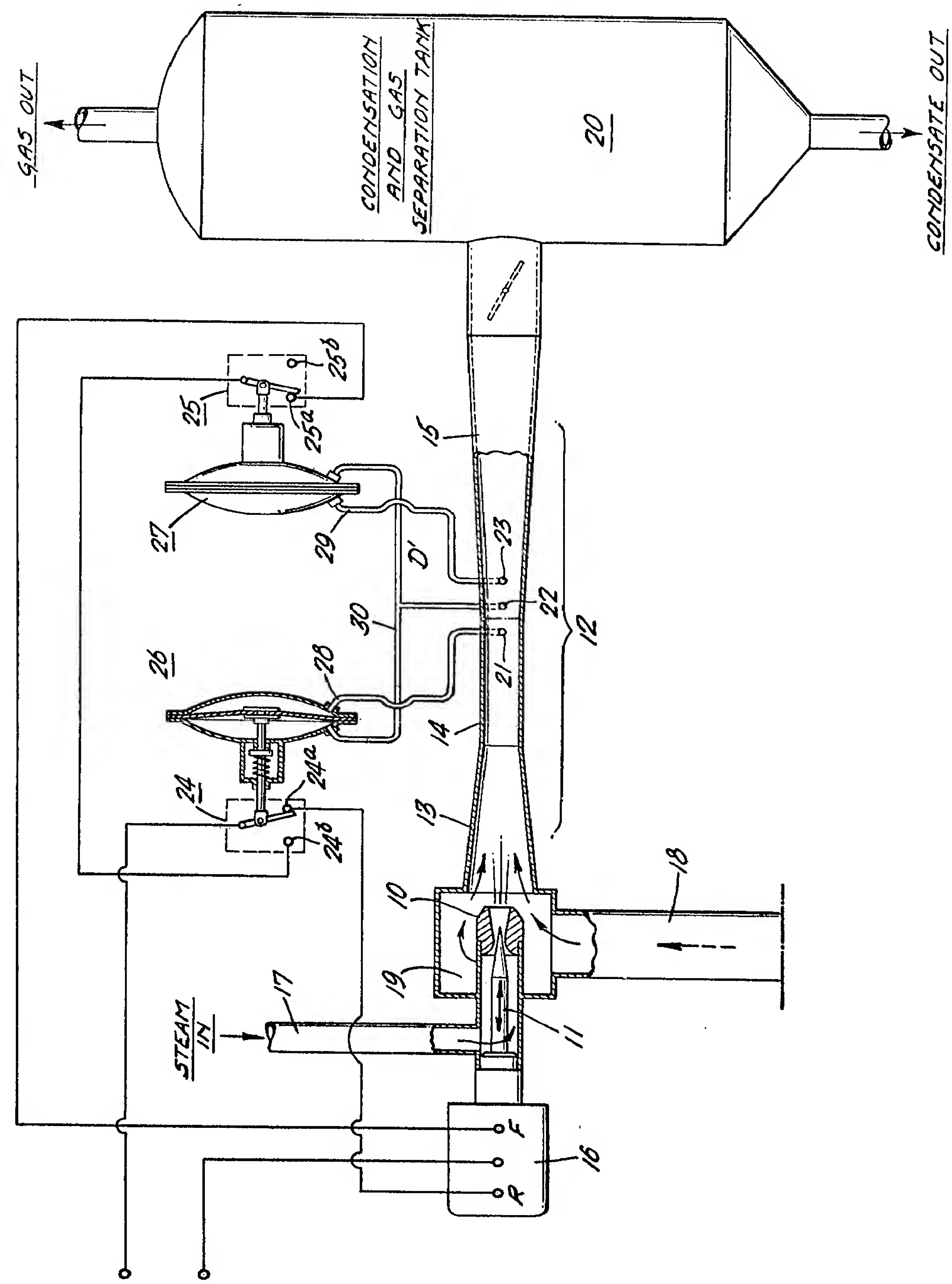

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FIG. 1.

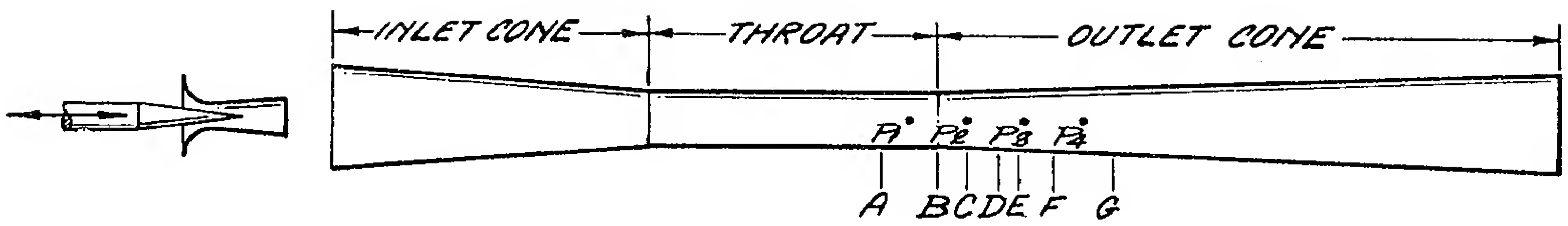


FIG. 1a.

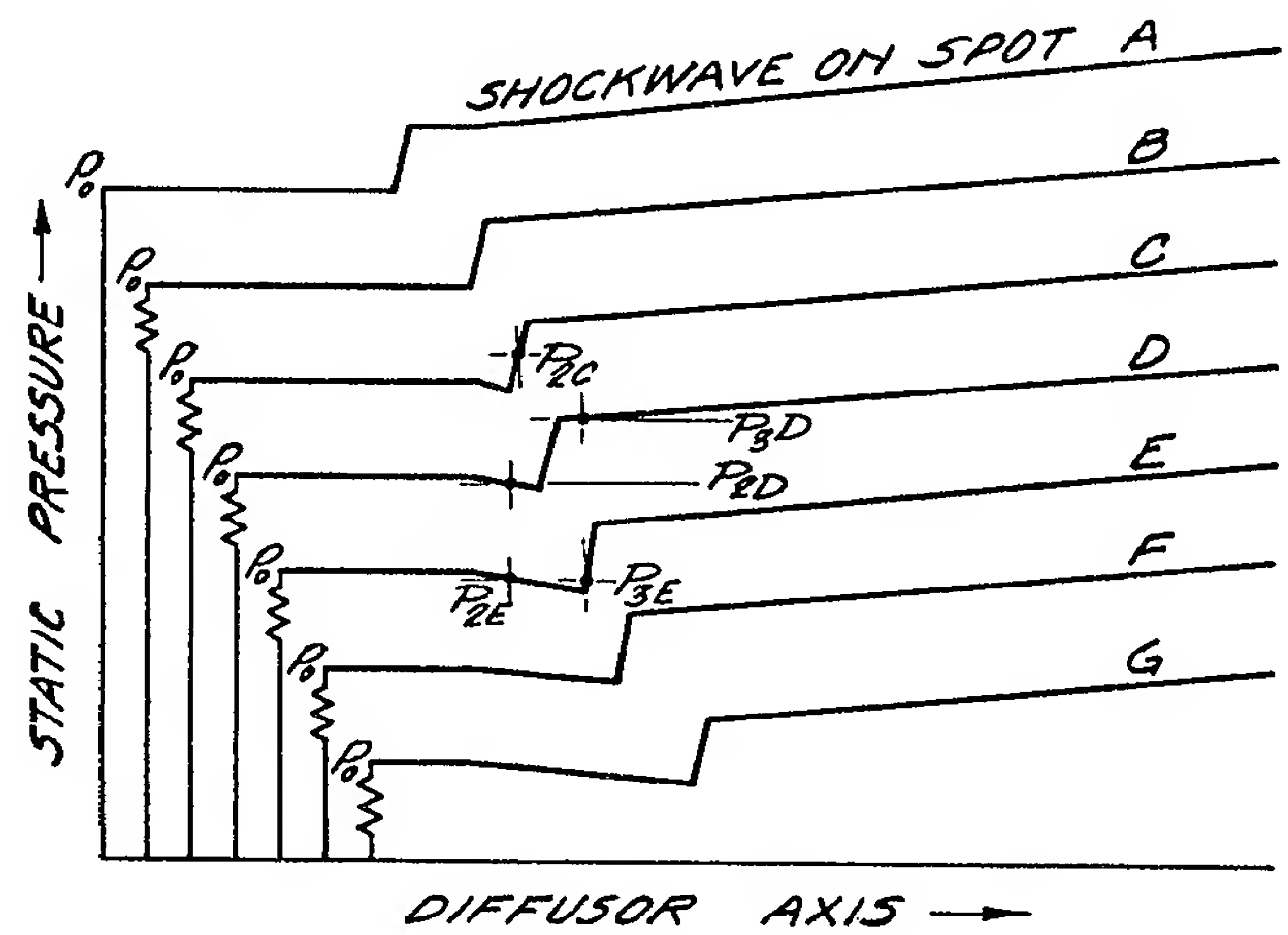


FIG. 2.

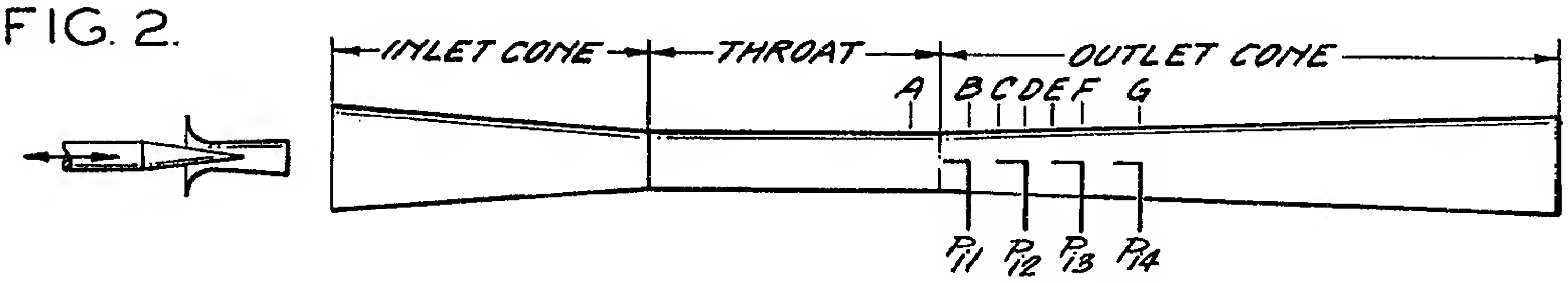
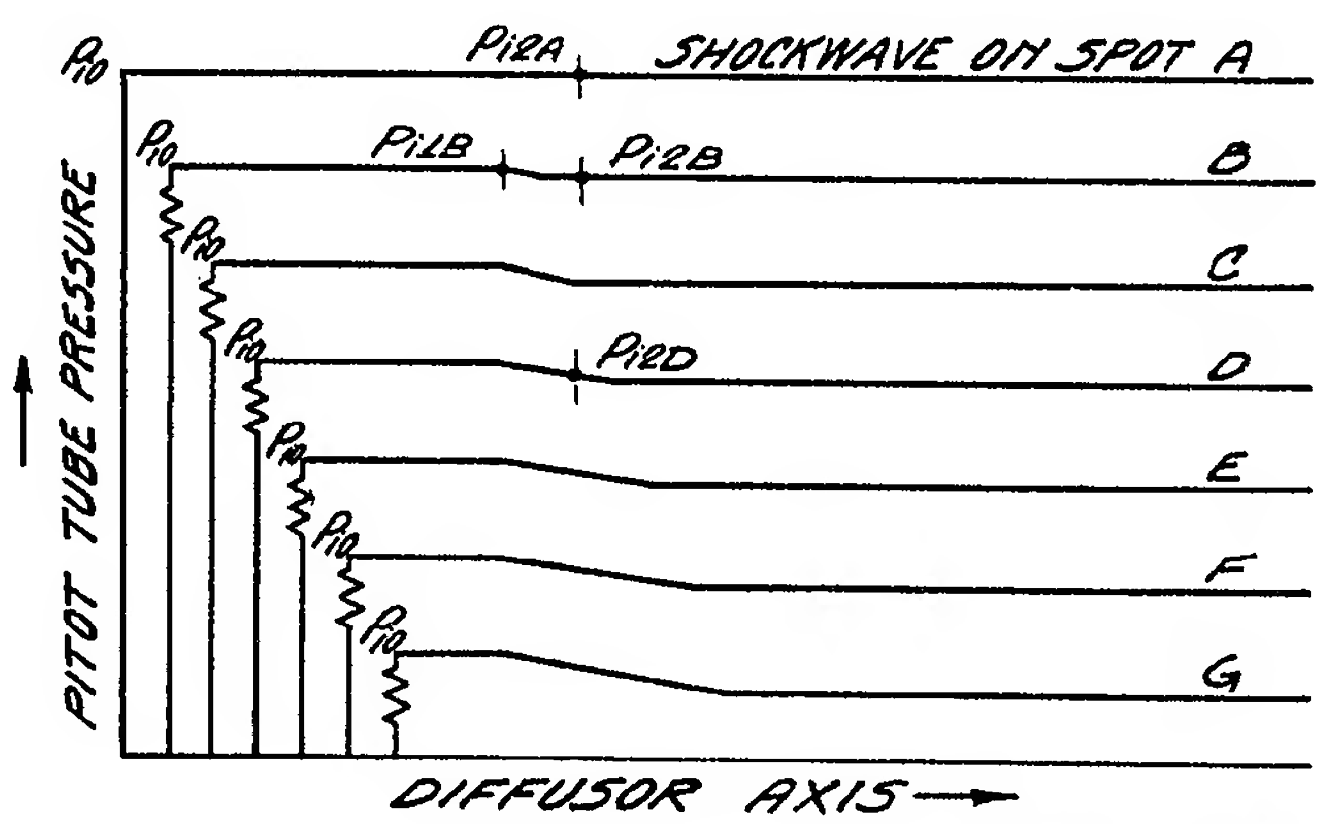


FIG. 2a.



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